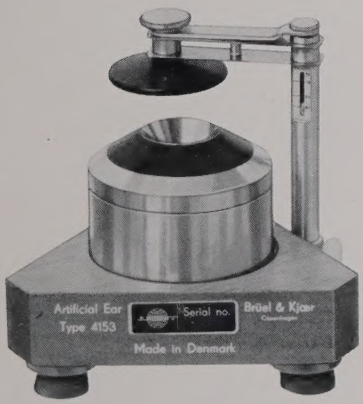
4153

INSTRUCTIONS AND APPLICATIONS

Artificial Ear Type 4153



The Artificial Ear is designed for electro-accoustical measurements on ordinary and circumaural headphones to be carried out under well defined acoustical conditions. It presents an acoustical load to the headphone being tested, which is basically similar to that of the human ear.

Accelerometers
Acoustic Standing Wave Apparatus
Artificial Ears
Artificial Voices
Audio Frequency Response Tracers
Audio Frequency Spectrometers
Audio Frequency Vacuum-Tube Voltmeters
Automatic A. F. Response and Spectrum Recorders
Automatic Vibration-Exciter Control Generators
Band-Pass Filter Sets
Beat Frequency Oscillators
Complex Modulus Apparatus
Condenser Microphones
Deviation Bridges
Distortion Measuring Bridges
Frequency Analyzers
Frequency Measuring Bridges
Hearing Aid Test Apparatus
Heterodyne Voltmeters
Level Recorders
Megohmmeters
Microphone Accessories
Microphone Amplifiers
Microphone Calibration Apparatus
Mobile Laboratories
Noise Generators
Noise Limit Indicators
Pistonphones
Polar Diagram Recorders
Preamplifiers
Precision Sound Level Meters
Recording Paper
Strain Gage Apparatus and Accessories
Surface Roughness Meters
Variable Frequency Rejection Filters
VHF-Converters
Vibration Pick-ups
Vibration Pick-up Preamplifiers
Wide Range Vacuum Tube Voltmeters

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Artificial Ear

Type 4153

March 1967

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0. Introduction

The Artificial Ear Type 4153 has been built in conjunction with the work of working group WG 11 of the International Electrotechnical Commission (I.E.C.), technical committee TC 29, on the standardization of an improved artificial ear for calibration purposes. It is the result of much careful research and development work at G.P.O. (General Post Office), N.P.L. (National Physical Laboratory) in Great Britain, and Brüel & Kjær, and presents an acoustical load to the headphone being tested, which is basically similar to that of the human ear. It enables electroacoustical measurements on headphones to be carried out under well defined acoustical conditions, which is of great importance for the comparability of different designs and the reproducibility of measurements.

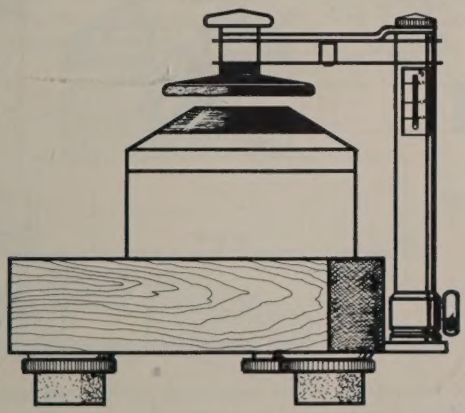


Fig. 1.1. The Artificial Ear Type 4153.

1. Description

General.

The Artificial Ear consists of a special coupler, a main housing containing the sockets for the connection of a 1/2" B & K condenser microphone and a base plate with clamping arrangement for the object being tested. Fig. 1.2 shows a sectional view of the Artificial Ear with the mounting arrangement for the condenser microphone and the cathode follower.

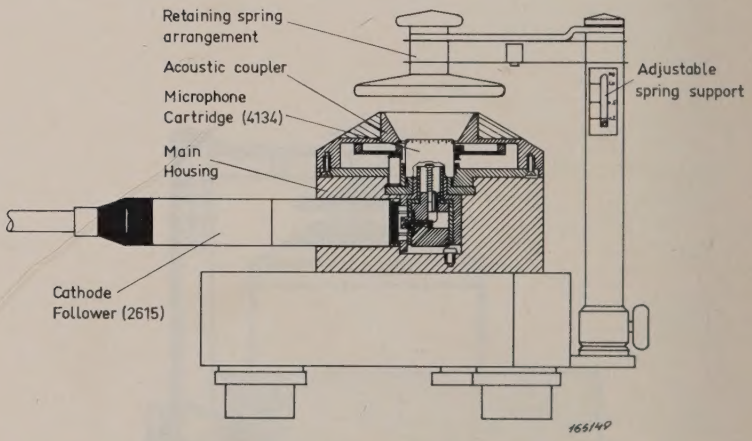


Fig. 1.2. Sectional view of the Artificial Ear.

The sockets for connection of the measuring microphone are made to fit a 1/2" Brüel & Kjær Condenser Microphone Cartridge Type 4134 and the associated Cathode Follower Type 2615. As indicating instrument a measuring amplifier or analyzer or the Precision Sound Level Meter Type 2203 may be used. In the latter case a special Adaptor, UA 0030, and an Extension Cable, AO 0033, should be mounted between the ear socket and the Sound Level Meter (Fig. 1.3).

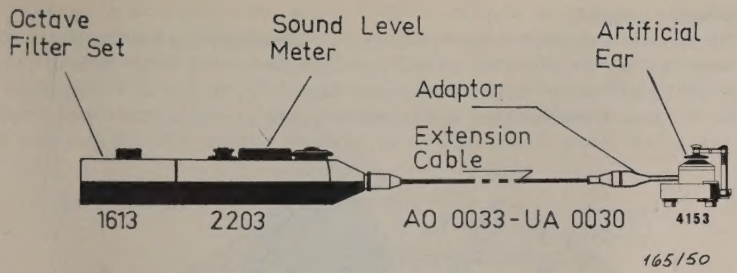


Fig. 1.3. The Artificial Ear used in connection with the Sound Level Meter Type 2203 and the Octave Filter Set Type 1613.

To avoid the influence of vibration during the measurements the Artificial Ear is vibration isolated by means of three soft rubber feet (see also Appendix A). In order to allow the user to make exact reproducible measurements for comparison with other couplers and ears a well defined high acoustic impedance sound source consisting of an Earcap YJ 0305 and an Adaptor AQ 0015 for a 1/2" Microphone Cartridge (which is then used as sound transmitter) is supplied with the Ear (Fig. 1.4)*). The sound source may also be used when measurements of the impedance of the human ear are to be carried out.

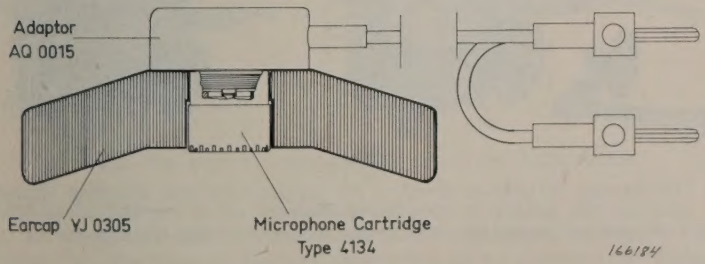


Fig. 1.4. Sectional view of the high acoustic impedance sound source.

*) A detailed description of the sound source is given in Appendix B.

Acoustic Coupler.

The acoustic coupler is a small rigid device containing three cavities (Fig. 1.5):
V_1*) = 2.5 cm³ which makes an acoustic capacity of 17.6×10^{-12} m⁵/N,
V_2 = 1.8 cm³ which makes an acoustic capacity of 12.7×10^{-12} m⁵/N and
V_3 = 7.5 cm³ which makes an acoustic capacity of 52.8×10^{-12} m⁵/N.

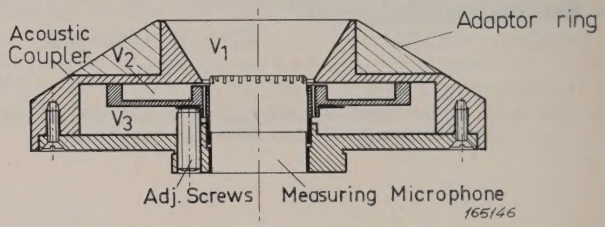


Fig. 1.5. Sectional drawing of the acoustic coupler showing the three cavities, the annular slit and the parallel holes.

The three cavities are acoustically connected in parallel by means of a narrow annular slit and four parallel holes. The slit and the four holes act as acoustic resistances of 6.5×10^6 Nsec/m⁵ and 20×10^6 Nsec/m⁵ respectively, while their acoustic inductances are 5×10^2 Nsec²/m⁵ for the slit and 10^4 Nsec²/m⁵ for the holes.

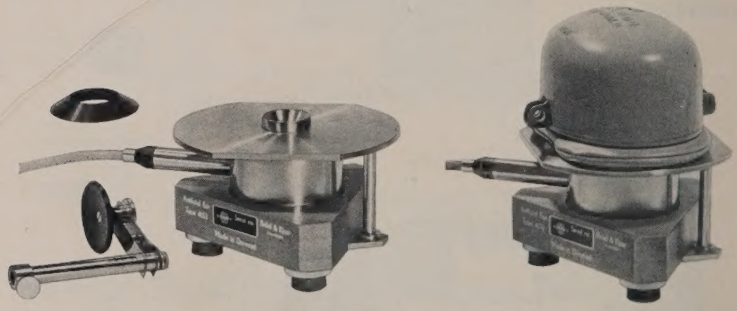


Fig. 1.6.
a) The Adaptor DB 0843 mounted on the Artificial Ear (the clamping arrangement and the Adaptor YJ 0304 are removed).
b) A circumaural sound damping device mounted on the Artificial Ear.

*) It should be noted that when the headphone to be tested is placed on the coupler, V_1 is increased with a certain volume dependent on the shape of the headphone. V_1 is 2.5 cm³ with a flat sheet placed on the coupler and with the measuring microphone mounted (including the equivalent volume of the cartridge).

A capillary tube arrangement which enables pressure equalization between the cavities and the surroundings is included in the coupler but this leakage has no influence on the volume of the cavities in the usable frequency range. The coupler is shaped so that it fits the 1/2" cartridge of the measuring microphone as well as the headphone under test. To allow circumaural headphones to be mounted on the coupler a special Adaptor DB 0843 is supplied (Fig. 1.6).

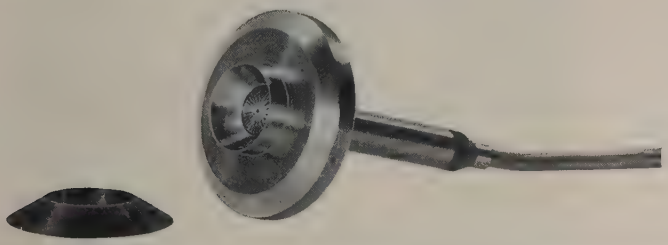


Fig. 1.7. The acoustic coupler mounted directly on a 1/2" condenser microphone with cathode follower.

If desired the acoustic coupler may be mounted directly on a 1/2" condenser microphone with cathode follower by means of the Adaptor ring DB 0742, also supplied, whereby an arrangement is obtained which is very small and easy to handle (Fig. 1.7).

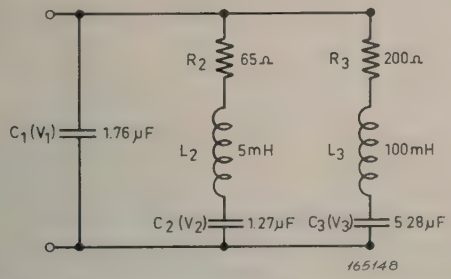


Fig. 1.8. The electrical equivalent circuit of the Artificial Ear.

Electrical Equivalence of the Acoustic Circuit.

Fig. 1.8 shows an electrical equivalent circuit impedance analogy of the Artificial Ear. The three cavities are represented by the capacitors C_1, C_2 and C_3 corresponding to the volumes V_1, V_2 and V_3 respectively. The slit is represented by an inductance L_2 in series with a resistor R_2, and the four holes by L_3 in series with R_3.

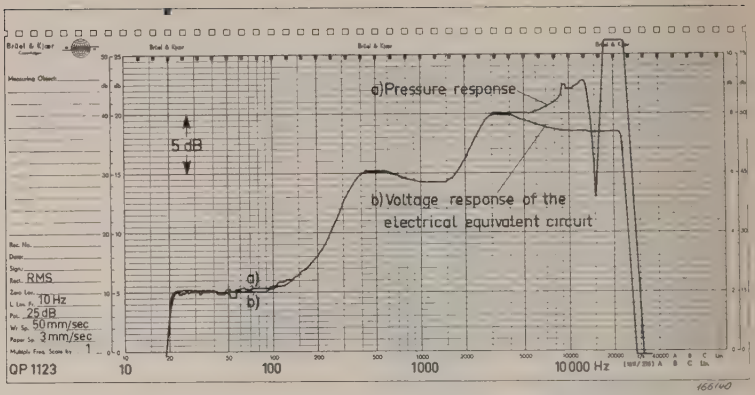


Fig. 1.9. Response curves for the Artificial Ear.
a) Pressure response.
b) Voltage response of the electrical equivalent circuit.

In Fig. 1.9 is shown the pressure response of the Artificial Ear as a function of frequency measured with a 1/2" Condenser Microphone Type 4134. The sound pressure is produced by the high impedance source described above which is fed from a constant AC voltage generator, and the acoustical coupling between the transmitting microphone and the Artificial Ear is established by pressing the Earcap against the Ear (Fig. 1.10).

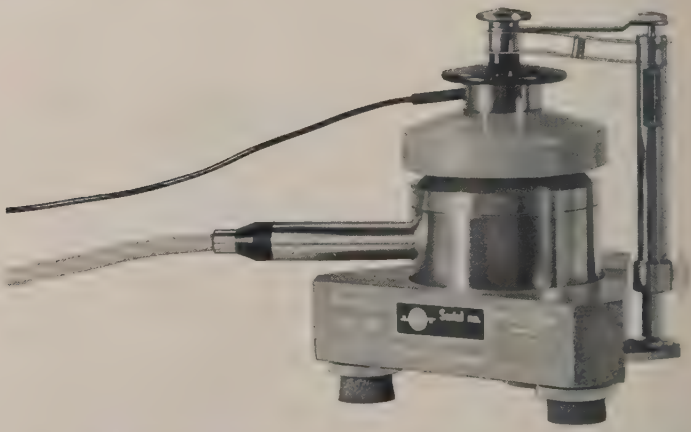


Fig. 1.10. The high acoustic impedance sound source mounted on the Artificial Ear.

For the sake of comparison, Fig. 1.9 also shows a curve of the voltage response of the electrical equivalent circuit fed from a constant voltage generator through a small capacitor. For frequencies above 4 kHz the curves do not coincide. This happens because the wavelength becomes comparable with the linear dimensions of the cavity V_1, and even smaller, so that standing waves will be introduced.

If the cartridge is driven without polarization voltage the sound pressure produced will have a frequency twice that of the generator (see appendix). This will, however, be of no practical importance as the frequency scanning of the instruments involved is logarithmic. The frequency range of the Beat Frequency Oscillator Type 1022 will in this case be 40–40,000 Hz.

With each Artificial Ear Type 4153 is supplied a calibration chart similar to that shown in Fig. 1.11.

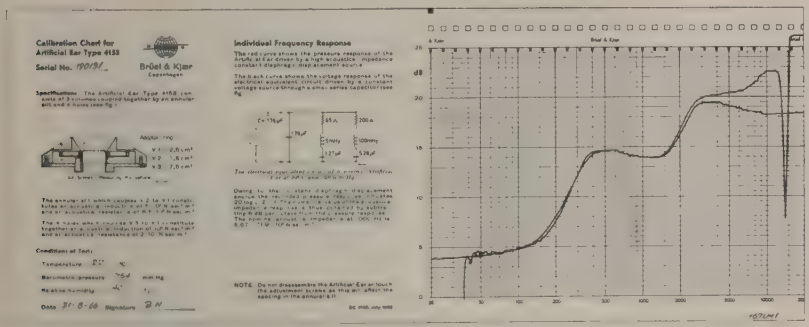


Fig. 1.11. Typical calibration chart for the Artificial Ear Type 4153.

Clamping Arrangement.

The clamping arrangement (see Fig. 1.2) is spring loaded and provided to apply a predetermined force which can be adjusted to about 2 N (0.2 kg force) or 5 N (0.5 kg force) as recommended by A.S.A. Standards, the actual force value being set on a scale engraved on the clamp holder.

If desired the clamping arrangement may be removed, e.g. when the special Adaptor DB 0843, designed to fit circumaural headphones, is used. A force may in this case be applied for instance by means of weights, but it should be noted that the maximum allowable force that may be applied to the top of the acoustic coupler is 10 N (1 kg force).

2. Operation

To carry out measurements by means of the Artificial Ear Type 4153 it should be fitted with a Microphone Cartridge Type 4134 and a Cathode Follower Type 2615 which should be connected to an indicating instrument. Instead of the cathode follower and the indicating instrument it is possible, as mentioned on p. 6, to use the Precision Sound Level Meter Type 2203.

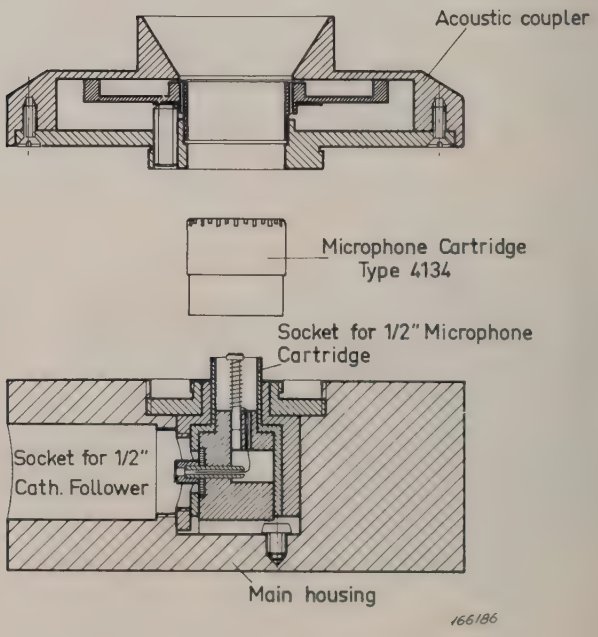


Fig. 2.1. Exploded view of the Artificial Ear.

Setting up of the Artificial Ear (see Fig. 2.1).

1. Unscrew the acoustic coupler.
2. Fit the Microphone Cartridge Type 4134 with protection grid to the microphone socket.
3. Replace the coupler onto the coupler socket.
4. Screw the Cathode Follower Type 2615 into the cathode follower socket.

Fig. 2.2. The Adaptors YJ 0304 and DB 0843.

5a. For testing *normal headphones* place the Adaptor YJ 0304 on the top of the coupler.
(It is possible to invert the Adaptor or to remove it in order to fit the shape of certain headphones but then this should be mentioned in the test specifications).

b. For testing *circumaural headphones* place the Adaptor DB 0843 on the top of the coupler.

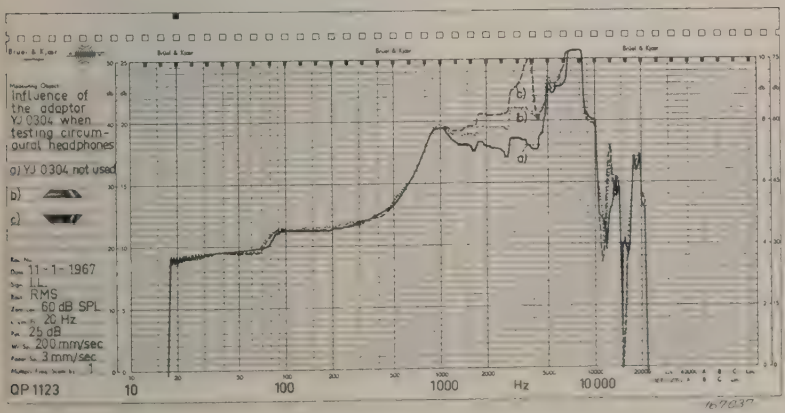


Fig. 2.3. Influence of the Adaptor YJ 0304 when testing circumaural headphones.
a) YJ 0304 is not used.
b) YJ 0304 is placed on top of DB 0843.
c) YJ 0304 is placed inverted on top of DB 0843.

The Adaptor YJ 0304 may be placed on top of this to simulate the human ear-lobe. The position can be either normal or inverted, and the choice should be mentioned in the test specifications. The influence of the Adaptor YJ 0304 is shown in Fig. 2.3.
(The clamping arrangement cannot be used with the Adaptor DB 0843).

6. Place the headphone to be tested on the top of the Artificial Ear.
7. If it is desired to apply a force to the headphone, proceed as follows:

a. Normal headphones: mount the clamping arrangement and adjust the height until the correct force value is read on the engraved scale.

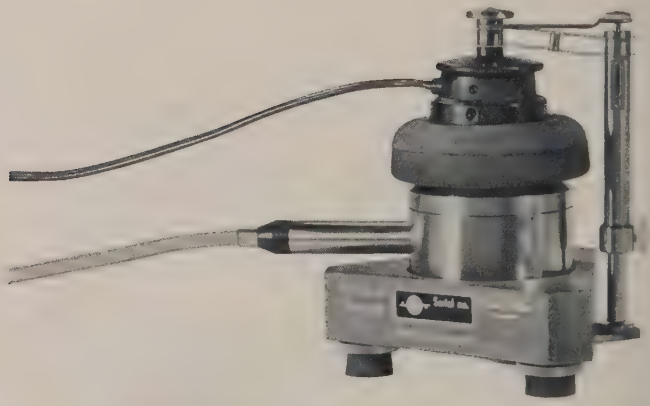


Fig. 2.4. A headphone mounted on the Artificial Ear ready to be tested.

b. Circumaural headphones: use weights, but the force must not exceed 10 N (1 kg force).

8. Connect a generator to the headphone and an indicating instrument to the cathode follower.

The Artificial Ear is now ready for use.

Operation of a Complete Arrangement for the Testing of Headphones.
Fig. 2.5 shows a typical measuring arrangement used to check the frequency characteristic of headphones. It consists of a Beat Frequency Oscillator Type 1022 built together with a Level Recorder Type 2305 and a Microphone Amplifier Type 2603.

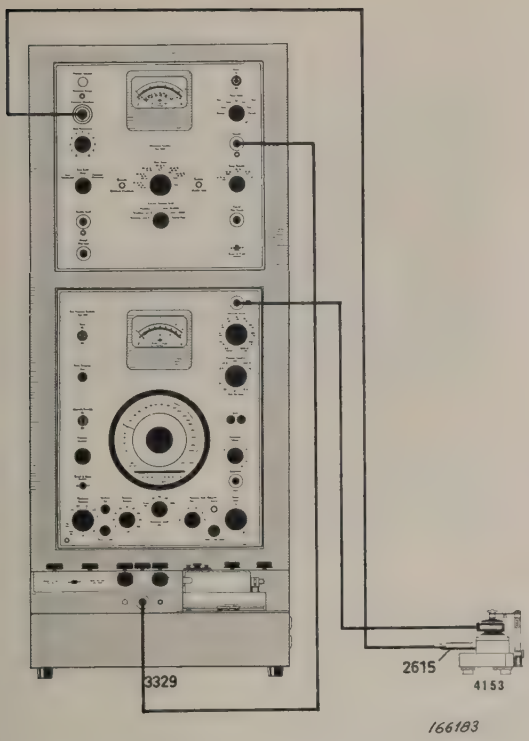


Fig. 2.5. Typical measuring arrangement for the production check of headphone characteristics.

The adjustment of the different instruments is made as follows:

Adjustment of the Oscillator.

1. Set the toggle switch marked POWER to »On« and allow two minutes to warm up.
2. MODULATION FREQUENCY, COMPRESSOR SPEED and AUTOMATIC SCANNING to their "Off" position.
3. Turn main scale pointer to 50 Hz.
4. Adjust the meter pointer by means of the knob marked OUTPUT LEVEL, until a deflection to higher than center scale is obtained.
5. Set the frequency incremental scale to – 50 Hz by means of the FREQUENCY INCREMENT knob.

6. Rotate FREQUENCY SCALE ALIGNMENT FINE slowly until the meter pointer falls to zero.
   If zero-deflection is not obtainable set FREQUENCY SCALE ALIGNMENT FINE at some point between 4 and 6 and adjust the variable capacitor marked COARSE by means of a screwdriver till zero-deflection is obtained.
7. Set the main scale pointer to the frequency of the line voltage (e.g. 50 or 60 Hz) and turn FREQUENCY INCREMENT till the frequency incremental scale is on zero.
8. While pressing the POWER FREQUENCY BEAT button rotate FREQUENCY SCALE ALIGNMENT FINE slowly until the fluctuation on the meter dial slows up and practically ceases.
9. Set the main scale pointer to 1000 Hz.
10. MATCHING IMPEDANCE switch to "Att.".
11. ATTENUATOR to the desired value.

Connect the attenuator output to the input terminals of the headphone to be tested.

Adjustment of the Microphone Amplifier.

1. Set the POWER switch to "On".
2. Check the microphone polarization voltage.
3. Connect the cathode follower in the Artificial Ear to the Microphone Amplifier.
4. Set the control knobs to the following positions:
   INPUT SWITCH: "Condenser Microphone".
   METER SWITCH: "Fast-RMS".
   METER RANGE: "Ref.".
   RANGE MULTIPLIER: "0 dB × 1".
   WEIGHTING NETWORK: "Linear, 2–40,000 Hz".
   Control knobs not mentioned can be in any position.
5. Allow 2 minutes to warm up.
6. Turn the SENSITIVITY-CONDENSER MICROPHONE potentiometer by means of a screwdriver until the meter pointer deflects to the red mark.
7. Connect the Microphone Amplifier to the Level Recorder.

The absolute value of the sound level is read as the deflection on the indicating meter + the number of dB SL indicated by METER RANGE + the number of dB indicated by RANGE MULTIPLIER + the correction factor "K" for the measuring microphone.
(If required further instruction can be found in the Instruction Manual for the Microphone Amplifier Type 2603 page 26–27, Microphone Cartridge Type 4134).

Adjustment of the Level Recorder.

50 dB potentiometer is used.

1. POWER and MOTOR toggle switches to "On".
2. POTENTIOMETER RANGE to "50".

3. RECTIFIER RESPONSE to "RMS".
4. LOWER LIMITING FREQUENCY to "20 Hz".
5. WRITING SPEED:
   160 mm/sec (large figures) with 50 mm paper, or 315 mm/sec (small figures) with 100 mm paper.
6. PAPER SPEED to "3 mm/sec" (small figures).

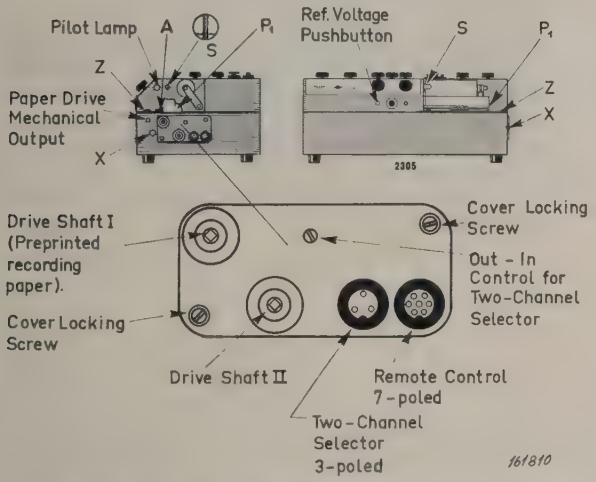


Fig. 2.6. Front and side view of the Level Recorder Type 2305.

7. Set the Synchronizing Gear Lever X in its outer position (see Fig. 2.6). Make sure that the Lever is pulled completely to the out position by moving the grooved finger wheel Z to and fro at the same time as pulling. (The actual paper drive speed now corresponds to the small figures marked around the PAPER SPEED knob).
8. PAPER DRIVE to "Start" and "Forward" commencing the paper to run, which will continue until the built-in automatic single chart stop switch declutches the drive mechanism (one chart length or less).
9. By means of the finger wheel Z adjust the paper until the recorder stylus is on the mark 10 Hz of the pre-calibrated recording paper.

Adjust the knob OUTPUT LEVEL on the Beat Frequency Oscillator until a sound pressure level of 100 dB in the Artificial Ear can be measured on the Microphone Amplifier, remembering to take the microphone "K" factor into account.

By means of INPUT POTENTIOMETER and INPUT ATTENUATOR of the Level Recorder, the deflection of the pen is adjusted to the 40 dB line of the recording paper. (The 40 dB line of the recording paper now corresponds with a sound pressure level of 100 dB in the Artificial Ear).
Turn the frequency scale pointer of the Oscillator to the ref. mark, that is to a position corresponding to the position of the recorder stylus on the pre-calibrated recording paper, and set AUTOMATIC SCANNING switch to "On" Lower the pen on the Level Recorder by the cam A (Fig. 2.6).
The recording can now be started by pressing the SINGLE CHART-CONT. RECORD. pushbutton for a short while and then releasing it again. The frequency characteristic will be recorded automatically on the paper strip. Normally headphones are measured under the conditions described above which are constant voltage conditions. However, by connecting a resistor in series with the headphone and using the voltage drop across this resistor to control the compressor circuit of the Oscillator constant current conditions can be obtained for the test.
In Fig. 2.7 is shown a typical recording of a headphone characteristic measured with the set-up described.

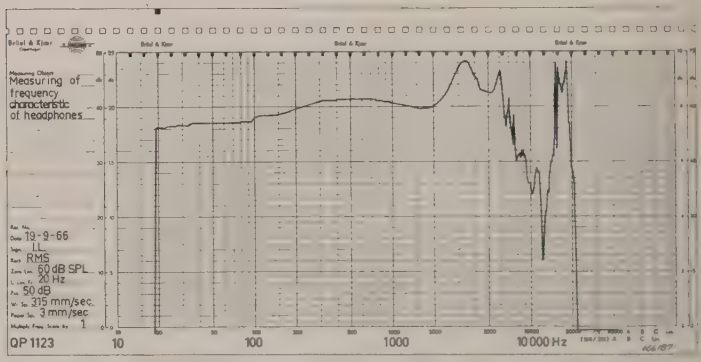


Fig. 2.7. Typical recording of the frequency characteristic of a headphone.

Calibration of a test set-up by means of a Pistonphone Type 4220.
With the coupler removed the Pistonphone is mounted on the Microphone Cartridge as shown in Fig. 2.8. The Pistonphone produces a sound pressure of 124 dB and the Level Recorder can be adjusted to give the corresponding deflection.

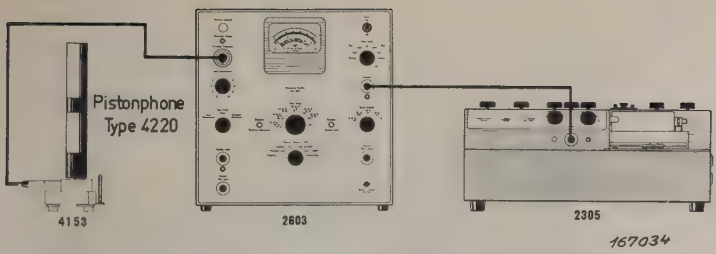


Fig. 2.8. Calibration of the set-up using the Pistonphone Type 4220.

This method of calibrating the test equipment is easier and more accurate than the one described above. Consequently if the user possesses a Pistonphone it is advisable to use it for the calibration.

3. Applications

Automatic Recording of Harmonics in Headphones.

By using the Artificial Ear Type 4153 together with an oscillator with low distortion, such as the B & K Beat Frequency Oscillator Type 1022, and the Audio Frequency Spectrometer Type 2112, an equipment well suited for measuring harmonics produced in headphones is obtained. If the Spectrometer

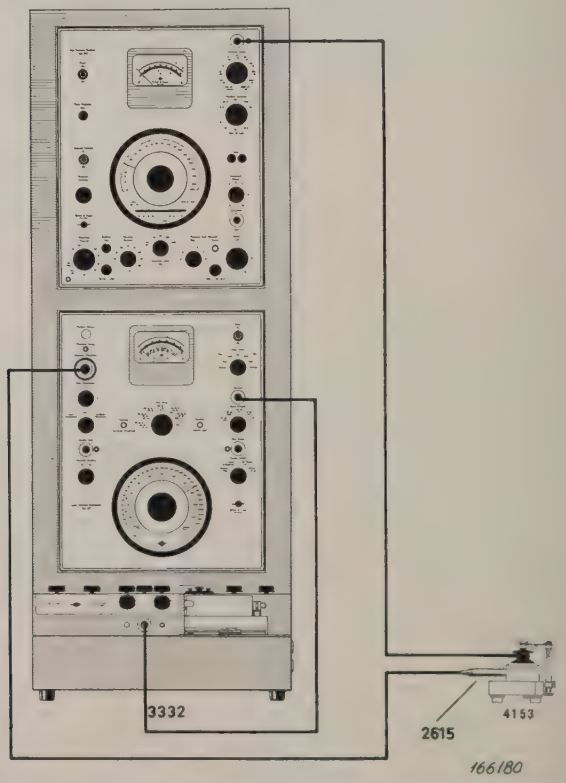


Fig. 3.1. Measuring arrangement for the automatic measurement of the frequency characteristic and harmonic distortion of headphones.

and the BFO are combined with the B & K Level Recorder Type 2305 (as in the Automatic Frequency Response and Spectrum Recorder Type 3332), the measuring arrangement (Fig. 3.1) can now automatically record the harmonics of the device under test on frequency calibrated recording paper.

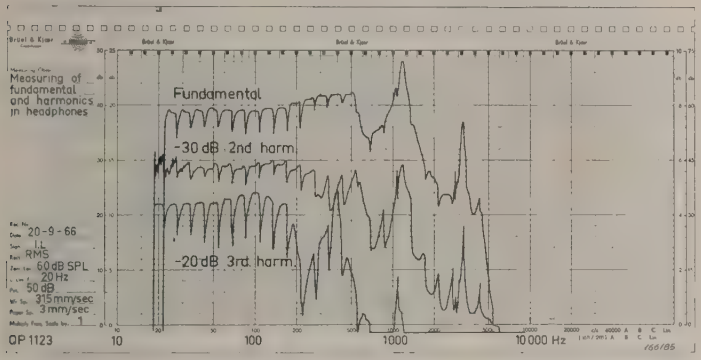


Fig. 3.2. Typical recording of the frequency characteristic ("Fundamental") and the 2nd and 3rd harmonic signals in a headphone.

In Fig. 3.2 the results of measuring the fundamental together with the 2nd and 3rd harmonics produced in a headphone are shown. They were measured by setting the filter switch on the Spectrometer so that it ran ahead of the frequency scanning of the BFO, the selected frequency difference being in accordance with the harmonic which was going to be measured. By means of the facility included in the Level Recorder Type 2305, which allows the recording paper to be reversed by one chart length without loosing the synchronization between the BFO and the Spectrometer, the harmonics are readily recorded on the same chart as the fundamental.

When measuring the 3rd harmonic of a signal it should be remembered that a slight mistuning between the frequency of the harmonic and the filter frequency of the Spectrometer will exist. This is due to the fact that a harmonic sequence is linear, whereas a sequence of 1/3 octave filters is logarithmic. The effect of this mistuning at the 3rd harmonic is indicated by the "dips" at the filter shifts being greater than under normal conditions. See Fig. 3.2.

Measurement of the Impedance of the Human Ear.

An interesting application of the Earcap YJ 0305 is the measurement of the pressure response of the human ear. A set-up for such a measurement is shown in Fig. 3.3 (the measurement is described in detail in B & K Technical Review No. 4/1961).

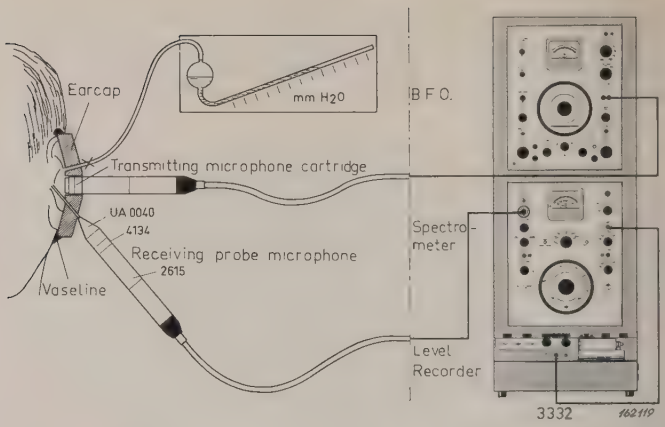


Fig. 3.3. Measuring set-up for measurement of the sound pressure at the channel entrance of a human ear using a 1/2" condenser microphone as transmitter and a probe microphone as receiver.

The Earcap, which is made of acoustically hard material, is placed against the human ear and to avoid any leakage vaseline is used for sealing. To be able to check the sealing, a pressure tube is led through a hole drilled in the Earcap through which a slight overpressure, of a few mm of water, can be obtained. The tube must be closed during measurement in order to avoid the influence of its compliance.

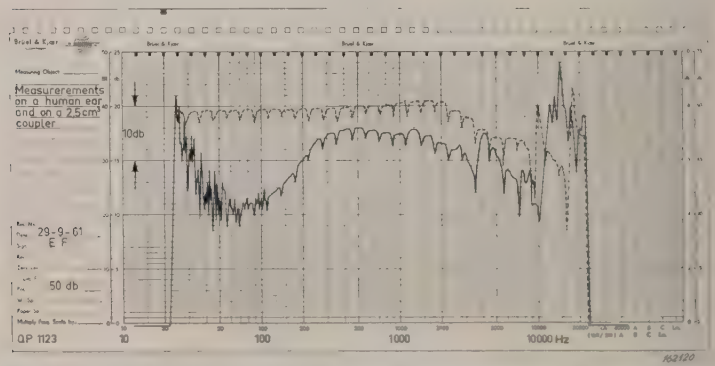


Fig. 3.4. Typical recording obtained from measurements on a human ear (full line) and on a simple 2.5 cm³ coupler (dotted line). Recorded by the set-up shown in Fig. 3.3.

The 1/2" transmitting microphone (Type 4134) is mounted in the center of the Earcap and driven with a constant AC voltage from the BFO while the signal from the receiving microphone is fed to the input of an Audio Frequency Spectrometer Type 2112. The receiving microphone, which is of the probe type and therefore should be calibrated before use, is led through a second hole in the Earcap and placed so that it measures the sound pressure at a point very close to the transmitting microphone. The Spectrometer measures the signal selectively in 1/3 octaves thus minimizing the effect of ambient noise and pressure variations due to movements of the person being tested. A typical pressure response curve is shown in Fig. 3.4 together with a reference recording of the sound pressure developed in a simple 2.5 cm^3 coupler (one cavity only).

Audiometer Calibration.

Accurate audiometers have become essential instruments in hospitals and schools as well as in industry because they allow full checks to be made of a person's hearing and possible hearing loss. The accuracy of an audiometer, however, very much depends upon the accuracy with which it is calibrated. Medical-legal litigation of hearing-loss claims calls for audiometric tests backed up by calibration data which will withstand expert critical review. Only a complete acoustical calibration of the audiometer at all compensable hearing levels, with the calibration referenced to an incontestable acoustic source, can withstand such a critical review. Also, since to move an audiometer may upset the instrument's calibration the calibration equipment itself must be made portable.

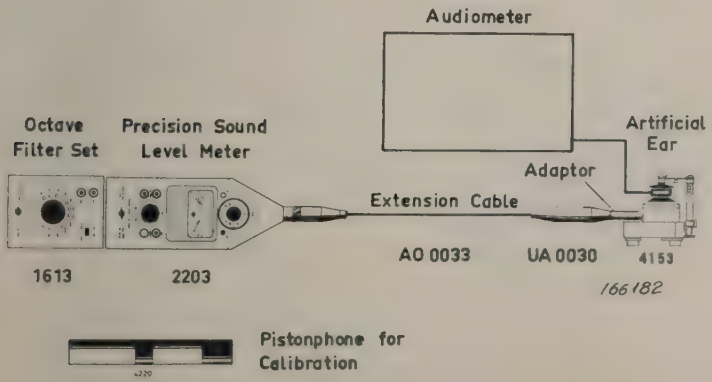


Fig. 3.5. Set-up for audiometer calibration.

An equipment (see Fig. 3.5) meeting these demands consists of an Artificial Ear Type 4153, a Precision Sound Level Meter Type 2203, an Octave Filter Set Type 1613, a Condenser Microphone Cartridge Type 4134, a Pistonphone Type 4220 and an input Adaptor UA 0030 with Extension Cable OA 0033. All these instruments as well as spare-batteries (and possible special noise measurement equipment) may be contained in the Carrying Case KE 0011.
The Pistonphone provides a rugged acoustical calibrator which will calibrate the Precision Sound Level Meter to an accuracy better than ± 0.2 dB at 250 Hz. Furthermore the accuracy of the Precision Sound Level Meter itself is in the order of ± 1 dB in the frequency range 20 Hz to 18,000 Hz. Sound levels can be measured from 68 to 148 dB and the preamplifier attenuator is variable in 10 dB steps over a 130 dB range. The accuracy of the attenuator is better than ± 2 % of the dial calibration.
Thus, by first calibrating the Precision Sound Level Meter by means of the Pistonphone and then using the Sound Level Meter together with the Artificial Ear for the actual audiometer calibration, an accurate and easy to operate audiometer calibrator is obtained.
To minimize the effects of ambient noise and structural borne vibration for low level acoustic calibration of the audiometer the Octave Filter Set may be incorporated in the calibration arrangement. The Filter Set contains 10 full octave filters with center frequencies from 31.5 Hz to 16,000 Hz, and the response is flat within ± 0.5 dB over 3/4 octave.
For further details on the Precision Sound Level Meter, the Octave Filter Set, the Condenser Microphone Cartridge and the Pistonphone the reader is referred to the specific Instruction Manuals.

Detailed Harmonic Analysis.
In cases where a detailed harmonic analysis of the sound pressure developed

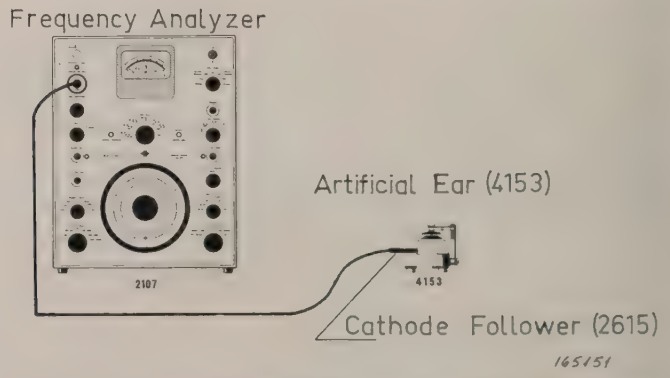


Fig. 3.6. Test set-up for detailed harmonic analysis of headphones.

by a headphone is of interest the Frequency Analyzer Type 2107 is a very suitable instrument. It is a selective voltmeter with an input socket designed for the use of condenser microphones and fitting the plug of the 1/2" cathode follower employed for the Artificial Ear (Fig. 3.6).
The narrow band-pass filter of the Analyzer is of the constant percentage bandwidth type, with a minimum bandwidth of 6 %. If the band-pass filter is "inverted" a very narrow band-stop filter is available suitable for measurements of low distortion factors.

Rapid Checks on the Frequency Characteristic of Headphones.
In the factory production of headphones, a rapid check of their frequency characteristic is often desired. A suitable set-up for this purpose is shown in Fig. 3.7.

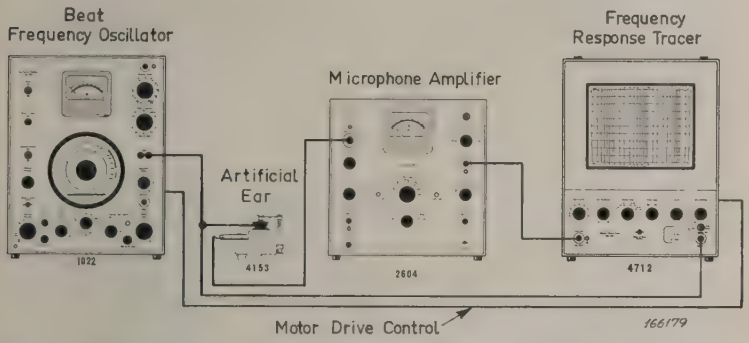


Fig. 3.7. Test set-up for checking the frequency characteristic of headphones.

A signal from the Beat Frequency Oscillator Type 1022 is fed to a headphone which is placed on the top of the Artificial Ear. The output from the microphone in the Artificial Ear is amplified in a Microphone Amplifier Type 2603 and fed to the Frequency Response Tracer Type 4712, where the frequency characteristic of the headphone is displayed on the screen of the cathode ray tube. Tolerance limits for the headphones under test may be drawn on the screen of the Frequency Response Tracer.

Appendix

A. Influence of Vibration.

When acoustical test are made on headphones care should be taken to minimize the effects of mechanical vibration of the Artificial Ear. Although the Ear is vibration isolated by means of three soft rubber feet large environmental vibrations may cause errors in the measuring results. Headphones, having a soft rubber ring to provide a good fit to the head of the listener, may be especially difficult to test as they can act as "accelerometers".

There are, however, several ways of overcoming the problem and some of them will be discussed in the following, viz. the use of foam rubber as damping material, the use of a selective measuring set-up and the mounting of the Artificial Ear in a vertical position thus minimizing the piston action of the headphone mass.

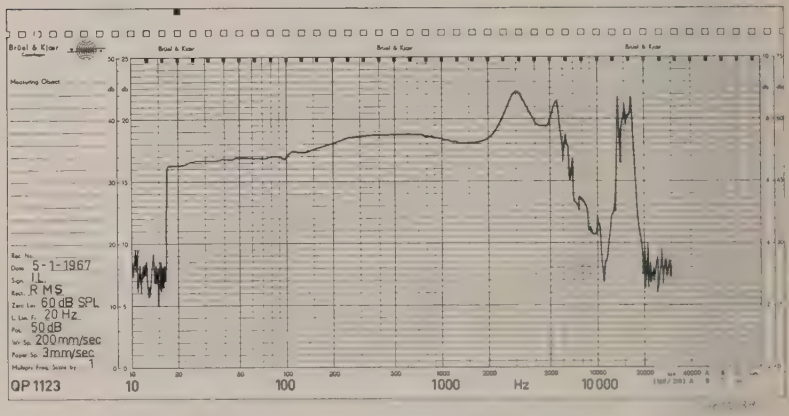


Fig. A1. Frequency characteristic of a headphone.

In Fig. A1 the frequency characteristic of a headphone is shown. The curve was measured by means of the set-up for automatic recording given in Fig. A2 switched for linear oparation in the frequency range 2–40,000 Hz. As can be seen from the curve the external noise and vibration has no influence on the response curve. The reason is that the disturbances are more than 10 dB below the signal level.

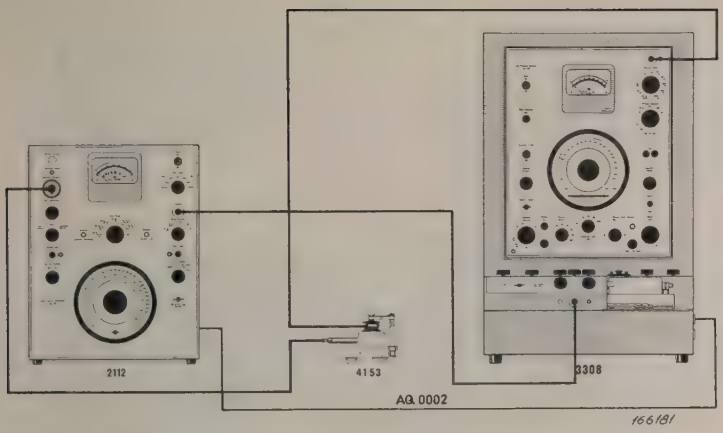


Fig. A2. Set-up for linear and selective measurement of the frequency characteristic of headphones.

Fig. A3.a shows the influence of an artificially produced low frequency vibration. The test conditions were, except for this vibration, exactly the same as mentioned above. As the disturbances are here only a few dB below the signal level they show a considerable influence on the response curve.

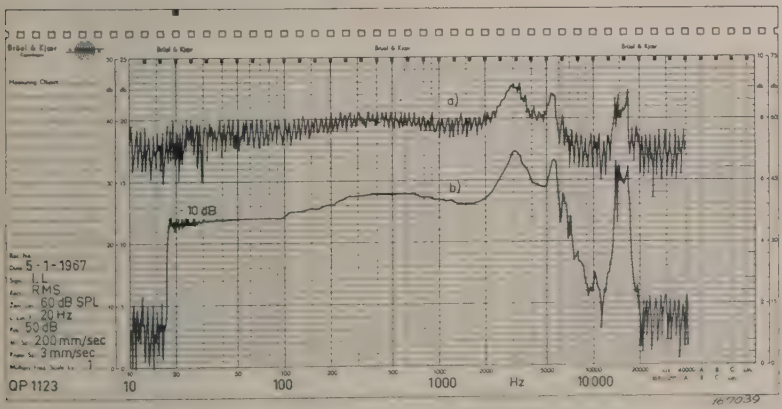


Fig. A3. Influence of vibration on the response characteristic.
a) The Artificial Ear stood on its rubber feet.
b) The Ear was placed on a foam rubber pad.

When the Artificial Ear is placed on a thick pad of foam rubber the vibration level is reduced by more than 10 dB and the influence again becomes negligible as can be seen in Fig. A3.b. The level of the curve b is attenuated by 10 dB so that the curves do not coincide. When using a foam rubber pad to dampen spurious vibration it is essential that the natural resonance of the pad itself, plus the mas upon it, is kept much lower than the lowest frequency in the disturbing vibration.

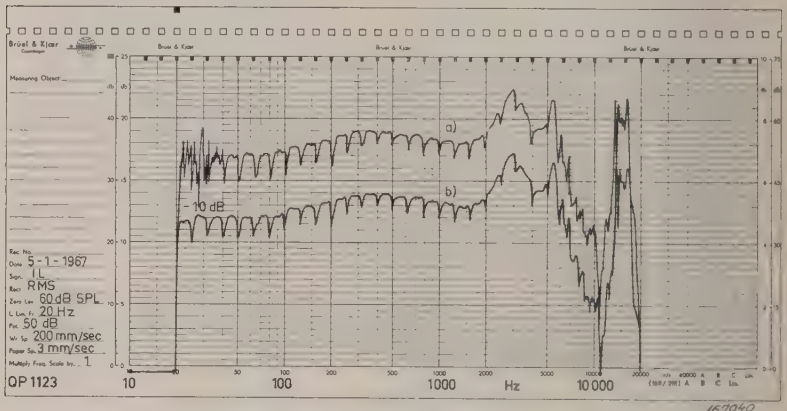


Fig. A4. Influence of vibration when measured through 1 3 octave filters.
a) The Ear stood on its rubber feet.
b) The Ear was placed on a foam rubber pad.

Another way of reducing the influence of vibration is to use a selective measuring set-up as shown in Fig. A2. The response characteristics recorded in Fig. A3 are in Fig. A4 shown measured under the same conditions but through 1/3 octave filters. It can be seen from the curves that when a relatively high vibration level is present a combination of foam rubber pad and selective measuring set-up will be very effective in reducing the influence of the disturbance.

The last method which has been investigated is the mounting of the Artificial Ear in a vertical position as shown in Fig. A5, where the arrangement is placed on a pad of foam rubber. In fig. A5a the complete Artificial Ear is mounted on the stand thus enabling the use of the clamping arrangement to keep the headphone in position. The base plate is removed in the arrangement shown in Fig. A5.b and here the headphone is kept in position by means of rubber bands.

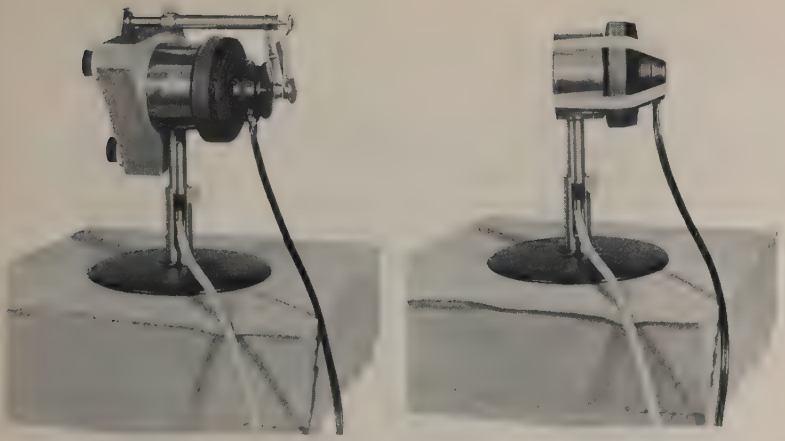


Fig. A5. The Artificial Ear mounted in a vertical position.
a) The complete Artificial Ear is mounted on the stand.
b) The base plate and the camping arrangement is removed. The headphone is kept in position by means of rubber bands.

It has been found that the influence of vibration will be considerably reduced when the test is made in this way on headphones which are made of hard material. However, the test on headphones having a very soft surface may not gain much advantage from the method and it is advisable that the user feels his way to arrive at the best way of reducing the influence of vibration in his specific case.

B. Use of Electrostatic Standard Earphone without Polarization.

In Fig. B1 an electrical circuit is shown where the microphone cartridge is used without polarization voltage but with a much higher alternating voltage e_i. In this way a considerably higher sound pressure can be obtained, but with twice the frequency of that impressed electrically upon the cartridge. The alternating voltage e_i should not be chosen higher than 220 V peak for the Microphone Cartridge Type 4134.

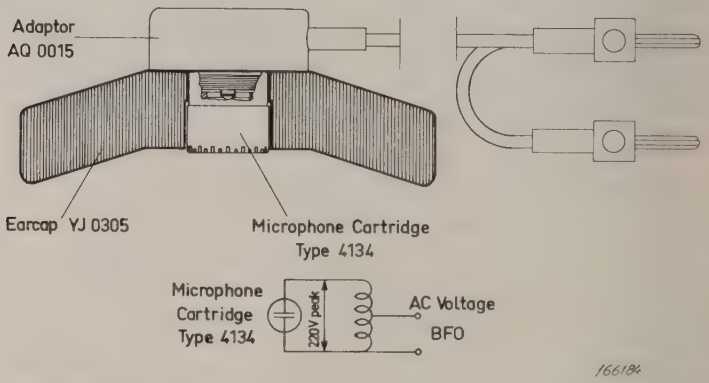


Fig. B1. Circuit and practical arrangement for the use of a condenser microphone as sound transmitter.

The force between the diaphragm and the back electrode in the earphone cartridge can generally be determined from the following expression:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5}\left(E_o^2 + \frac{e_i^2}{2} + 2\,E_o\,e_i \sin \omega t - \frac{e_i^2}{2}\cos 2\,\omega t\right) \text{N}$$

where S is the effective surface area of the diaphragm and the back electrode in m^2, d is the distance between the diaphragm and the electrode in m, E_o is the polarization voltage in volts (normally 200 V) and e_i is the peak value of the alternating sinusoidal voltage impressed upon the cartridge. The RMS value of the alternating voltage is $e_{RMS} = \frac{e_i}{\sqrt{2}}$.

From this expression it is easily seen that the 2nd harmonic distortion is $\frac{e_i}{4\,E_o} \times 100 = 35.3\,\frac{e_{RMS}}{E}$ %. If we require a distortion limit of 1 % and have a polarization voltage of 200 V, the maximum RMS alternating voltage which can be used will be 5.7 volts. As the Beat Frequency Oscillator at high fre-

quencies can have a distortion of up to 0.5 %, it is only possible in practice to use approximately 4 volts in order not to exceed the distortion limit of 1 % in the produced sound. The driving alternating peak force will then be:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times 2 \times 200\sqrt{2} \times 4 = \frac{S}{8\,\pi\,d^2\,300^2\,10^5}\,2260\ \text{N}$$

When the microphone cartridge is driven without polarization voltage, but with 220 V AC peak, the DC component will be:

$$e_{RMS} = \frac{e_1}{\sqrt{2}} = \frac{220}{\sqrt{2}} = 156\ \text{V}$$

It is possible to obtain a pure sinusoidal sound pressure under the assumption that the impressed voltage from the Beat Frequency Oscillator is without distortion. Normally it is necessary to take the small amount of 2nd and 3rd harmonics, which practically every BFO will produce into consideration. The voltage from the oscillator can in general be written:

$$e = e_1 \sin \omega_1 t + e_2 \sin \omega_2 t$$

where e_1 = amplitude of the fundamental electrical voltage with angular frequency ω_1.
e_2 = amplitude of the distortion component with the angular frequency ω_2.
ω_2 = in practice either the 2nd or the 3rd harmonic.

The force will be:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5}\,(e_1 \sin \omega_1 t + e_2 \sin \omega_2 t)^2$$

$$= \frac{S}{8\,\pi\,d^2\,300^2\,10^5}\left[\frac{e_1^2}{2} - \frac{e_1^2 \cos 2\,\omega_1 t}{2} + \frac{e_2^2}{2} - \frac{e_2^2 \cos 2\,\omega_2 t}{2}\right.$$

$$\left. + e_1 e_2 \cos(\omega_1 - \omega_2)\,t - e_1 e_2 \cos(\omega_1 + \omega_2)\,t\right]\ \text{N}$$

It can be seen from the expression that a 2nd or 3rd harmonic in the electrical voltage will produce twice the amount of disturbing frequencies in the sound pressure. This is clearly indicated in Table 1, where the produced side band frequencies are also shown.

	Distortion	BFO electrical		Sound in Earphone		
Frequency	2nd harmonic	f	2 f	2 f	f	3 f
Amplitude		100 %	1 %	100 %	2 %	2 %
Frequency	3rd harmonic	f	3 f	2 f	2 f	4 f
Amplitude		100 %	1 %	100 %	2 %	2 %

Table 1.

The Beat Frequency Oscillator Type 1022 will give maximum 0.5 % 2nd and 3rd harmonics under the most unfavourable conditions, i.e. the maximum side band frequencies obtainable in the sound pressure using the cartridge without polarization voltage will be 1 %. For the 2nd harmonic the side band can easily be distinguished but for the 3rd harmonic one of the side band frequencies will be just equal to the "fundamental" frequency and give a maximum uncertainty of 1 % on the amplitude for this frequency.

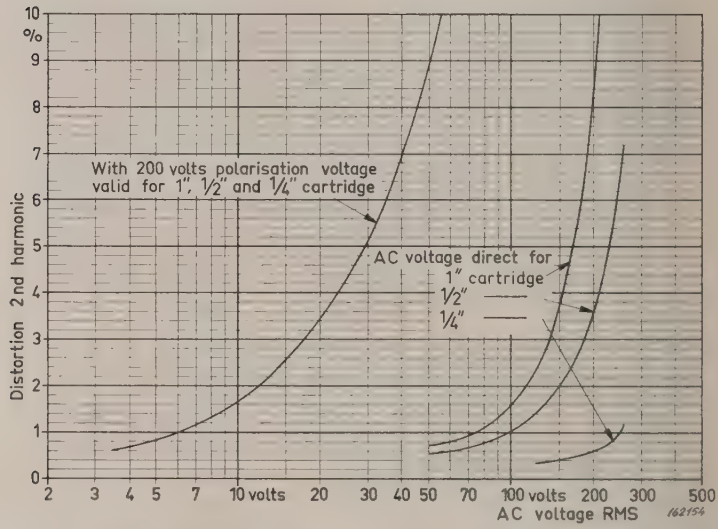


Fig. B2. Second harmonic distortion for 1", 1/2" and 1/4" condenser microphones driven
a) in the conventional way
b) by pure AC, plotted against RMS driving voltage.

At high amplitudes where the displacement of the diaphragm becomes large compared to the distance between diaphragm and electrode, distortion will take place and reduce the maximum output to some degree. In Fig. B2 distortion curves measured for different types of microphone cartridges are shown and compared to the distortion produced in a cartridge due to the ratio between the AC and polarization voltages. It can be seen that the distortion, due to the large vibration amplitudes, depends upon the type of cartridge used. The distortion versus applied voltage is inversely proportional to the sensitivity of the cartridge.

If an RMS voltage of 156 V is impressed on the 1/2" cartridge the alternating peak force obtained between the electrode and the diaphragm will be:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times \frac{(156\sqrt{2})^2}{2} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times 24{,}300\ \text{N}$$

In Fig. B2 it can be seen that the distortion will be 2.1 % at 156 V RMS. This corresponds to the distortion of a cartridge driven with 200 V polarization voltage and an RMS voltage of around 12 V. The force produced in this way will be:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times 2 \times 200\sqrt{2} \times 12 = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times 6{,}780\ \text{N}$$

The sound pressure produced by the cartridge driven with a pure AC voltage is consequently about 11 dB higher than that obtained with the normal polarization voltage at an equal distortion level (2.1 %).
If maximum distortion is limited to 1 % for a 1/2" cartridge a maximum AC voltage of only 100 V RMS is appliable and this results in a force between the electrode and the diaphragm of:

$$\text{Force} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times \frac{(100\sqrt{2})^2}{2} = \frac{S}{8\,\pi\,d^2\,300^2\,10^5} \times 10{,}000\ \text{N}$$

i.e. about 13 dB higher sound pressure than that obtained with the normal polarization voltage (ref. page 31). To use only 100 V AC on the cartridge corresponds to 100 V polarization voltage, and the frequency response is here slightly different from normal (200 V polarization voltage), see Fig. B3.

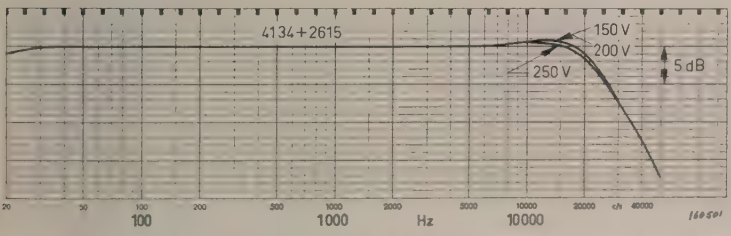


Fig. B3. Change in frequency response of the Microphone Cartridge Type 4134 for various polarization voltages.

Owing to the frequency doubling a "standard" beat frequency oscillator will produce sound of frequencies up to 40 kHz. As the Brüel & Kjær Beat Frequency Oscillator Type 1022 has a completely logarithmic scale, there is no disadvantage introduced with the frequency doubling except that it will not now supply frequencies less than 40 Hz.

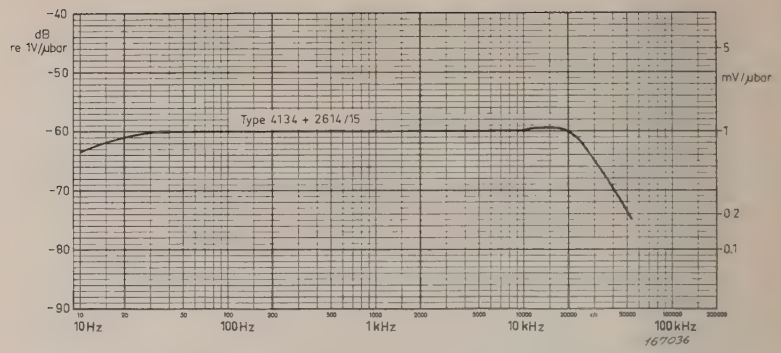


Fig. B4. Pressure frequency response of the B & K 1/2" Condenser Microphone Type 4134. The cartridge used as transmitter will give a constant volume displacement within the range 20 Hz – 20 kHz.

In Fig. B4 the sound pressure which the standard earphone will produce in a very small chamber is shown. The curve is taken with an electrostatic actuator and shows the frequency response of the cartridge used as a microphone, but it represent exactly the sound pressure transmitted into a capacitive acoustical impedance.

SPECIFICATIONS

Measuring microphone*): B & K Condenser Microphone Cartridge Type 4134.
Cathode follower*): B & K Cathode Follower Type 2615.

Output impedance from the cathode follower: Approximately 750 Ω.

Cavities:

	volume	acoustic capacity
V_1	2.5 cm^3 ± 3 %	17.6 × 10^{-12} m^5/N
V_2	1.8 cm^3 ± 3 %	12.7 × 10^{-12} m^5/N
V_3	7.5 cm^3 ± 3 %	52.8 × 10^{-12} m^5/N

Connections between Cavities:

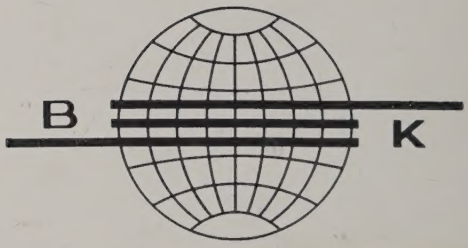
	acoustic resistance	acoustic inductance
Annular slit	6.5 × 10^6 $Nsec/m^5$	5 × 10^2 $Nsec^2/m^5$
Four parallel holes	20 × 10^6 $Nsec/m^5$	10^4 $Nsec^2/m^5$

Maximum force applied to the top of the acoustic coupler: 10 N (1 kg force).

Dimensions:
Max. diameter: 123 mm
Height: 104 mm
Weight: 1.0 kg

Accessories included:
1 Earcap YJ 0305
1 Adaptor AQ 0015
1 Adaptor DB 0742
1 Adaptor DB 0843

*) The measuring microphone and the cathode follower are not supplied with the Artificial Ear.



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